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<p>(21) International Application Number: PCT/NO00/00158</p> <p>(22) International Filing Date: 12 May 2000 (12.05.00)</p> <p>(30) Priority Data: 19992360 14 May 1999 (14.05.99) NO</p> <p>(71) Applicant (for all designated States except US): OFFTECH INVEST AS [NO/NO]; N-4035 Stavanger (NO).</p> <p>(72) Inventors; and (75) Inventors/Applicants (for US only): REINHART, Kevin [NO/NO]; Holstsgt. 4A, N-0473 Oslo (NO). OSEN, Per [NO/NO]; Jegerveien 18 F, N-0777 Oslo (NO). SEMB, Gunnar [NO/NO]; Brentedalen 8, N-4800 Arendal (NO).</p> <p>(74) Agent: TANDBERGS PATENTKONTOR AS; Boks 7085, N-0306 Oslo (NO).</p>		<p>(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).</p> <p>Published With international search report.</p>
<p>(54) Title: A FLEXIBLE LIGHTWEIGHT COMPOSITE PIPE FOR HIGH PRESSURE OIL AND GAS APPLICATIONS</p>		
<p>(57) Abstract</p> <p>A flexible lightweight high pressure pipe for riser or pipeline applications, especially offshore, comprising an internal liner (3), a first structural layer (4) applied to the internal liner, for absorbing pressure loads, one or more additional structural layers (5, 6) applied to the first structural layer (4), for absorbing axial and bending loads, and a fluid-tight external cover (7). Both the first structural layer (4) and the additional structural layers (5, 6) are manufactured from a lightweight composite material consisting of a fibre-reinforced matrix, the first structural layer (4) being a solid layer reinforced by long continuous fibres (8) extending around the pipe (1), and each of the additional structural layers (5, 6) consisting of a plurality of individual strips (11) reinforced by fibres extending essentially in the longitudinal direction of the strips, and which are wound around the pipe (1), but are not bonded to the adjacent strips (11) or to the layers (4, 7) above or below these.</p>		

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A flexible lightweight composite pipe for high pressure oil and gas applications

5 The invention relates to a flexible lightweight high pressure pipe for riser or pipeline applications, especially offshore, comprising an internal liner, a first structural layer applied to the internal liner, for absorbing pressure loads, one or more additional structural layers applied to the first structural layer, for absorbing axial and bending loads, and a fluid-tight external cover, wherein at least the first and the
10 additional structural layers are manufactured from a lightweight composite material consisting of a fibre-reinforced polymer matrix.

For high pressure offshore riser and pipeline applications, there exists several types of pipe constructions. The two main categories are rigid pipes (metallic and non-metallic), and fully non-bonded flexible pipes.

15 Rigid pipes have a high axial and bending stiffness and are constructed with a solid pipe wall which withstand all design loads. These pipes may be used for riser or pipeline applications, and are usually used in a jointed configuration. The riser or pipeline is assembled of separate sections joined by welding, bolting, threading, or other connection mechanisms. These pipes may be constructed of metallic materials, or
20 of lightweight composite materials. Pipes of composite materials are not yet used for riser applications, but are under development. However, these pipes are based on bonded composite technology, which results in a pipe which has high strength, but also high stiffness.

 A traditional non-bonded flexible pipe consists of an internal
25 thermoplastic liner reinforced by multiple metallic structural layers, with an external thermoplastic cover. Each structural layer of this pipe is constructed of multiple discrete strips wound helically on the pipe. The strips are not bonded, and can move relative to each other. The structural layers can be described according to their function, viz. an internal carcass used to withstand external pressure, one or more layers to withstand
30 internal pressure, and multiple layers to withstand axial and bending loads. For many offshore riser applications, rigid pipes are not suitable because of the high bending

flexibility required. In these applications, flexible risers are often used. However, oil and gas production are occurring at deeper and deeper waters. In very deep water (greater than 1000 meters) traditional flexible pipes which incorporate metallic structural layers, experience problems with high self-weight of the riser. One way to solve this weight problem, is to add external buoyancy elements along the riser for support, but buoyancy elements increase the loads on the riser caused by currents, and are themselves very expensive.

Another solution is to replace the metallic strips of the structural layers of a flexible riser with strips made of a lightweight composite material. This composite takes the form of unidirectional fibre reinforced polymeric material. There are currently projects ongoing to manufacture and qualify non-bonded flexible pipes which incorporate composite strips in some of the structural layers. For dynamic offshore applications, this solution to date is only suitable for the layers used to withstand axial and bending loads. These layers consist of strips wrapped on the pipe at angles between 10° and 45° to the longitudinal axis of the pipe. Incorporation of composite materials in these layers reduces the total weight of the riser. However, replacement of the pressure load bearing layer with composite strips has not been achieved. Therefore, although lighter than traditional flexible pipe, the pipe requires a metallic pressure load bearing layer that still has a significant weight, limiting the potential areas of application.

For a traditional flexible pipe, the metallic strips of the pressure load bearing layer are wrapped on the pipe at angles between 65° and 90° to the longitudinal axis of the pipe. In order to maintain a constant distance between the metallic strips, these are formed with an interlocking shape (either an "S"-shape or a "C"-shape) which prevents excessive axial movement. This results in concentrated transfers loads and stresses in the strip when the pipe is bent or stretched axially. While a metallic material can withstand these stresses, this is not the case with a composite strip manufactured from a unidirectional reinforced polymer, and it is therefore not suitable for this design.

A flexible pipe structure of the introductorily stated type is known from US patent publication 5 261 462. The pipe according to this patent is a flexible composite pipe for static onshore applications within the oil industry. The pipe has one or more structural layers to withstand internal pressure, and additional structural layers

having the function to absorb axial and bending loads. All structural layers consist of a plurality of individual fibre-reinforced strips wrapped around the pipe, but are not bonded to the adjacent strips or to the layers above or below these. Also the first structural layer here consists of non-bonded strip wrapped around the pipe at an angle close to 90° to the longitudinal axis of the pipe. This gives some advantages, but has several drawbacks associated with forces and stresses between the individual strips in this structural layer. A composite strip manufactured from unidirectional reinforced polymer will not effectively be able to withstand the transverse stresses which will occur under high bending loads. Thus, this known pipe is not suitable for application as a dynamic, flexible high pressure riser, since the pressure load bearing layer is not capable of withstanding large dynamic axial deformations.

On this background it is a general object of the invention to provide a flexible high pressure pipe which is suitable for riser and pipeline applications, especially offshore, and which comprises lightweight composite materials in both the pressure load bearing layer and the axial and bending load bearing layers of the pipe.

A more particular object of the invention is to provide a lightweight high pressure composite pipe which is able to withstand high bending deformations, and which is suitable for applications requiring a high bending flexibility.

For achieving the above-mentioned objects there is provided a flexible high pressure pipe of the introductorily stated type which, according to the invention, is characterized in that the first structural layer is a solid layer which is reinforced by long continuous fibres extending around the pipe, so that the layer has a high strength in the hoop direction of the pipe, and that each of the additional structural layers, as known per se, consists of a plurality of individual strips reinforced by fibres extending essentially in the longitudinal direction of the strips, and which are wound around the pipe, but are not bonded to the adjacent strips or to the layers above or below these.

By combining a solid structural layer with a plurality of non-bonded structural layers in the manner stated above, the invention allows the use of a lightweight composite material in both the pressure load bearing structural layer and the axial and bending load bearing structural layers of the pipe, something which results in a flexible pipe having a much lower weight than the traditional pipe. Because of the low

density of most of the materials used in the pipe, the pipe will have an extremely low submerged weight.

Due to the low weight, the riser according to the invention will also allow operations at greater water depths than what is permitted with traditional flexible pipes. In addition to the operational benefits, the low weight of the pipe will facilitate the installation, by reducing the size of equipment required to lift and bend the pipe. This applies both when the pipe is used as a riser, and when it is used as a static pipeline.

For typical riser applications, the low weight of the pipe design allows easier optimization of the riser configuration. In some cases it may be necessary to add additional weight along the length of the pipe, but it will be possible to position the weight where it is required. This is in contrast to a heavier riser which has a greater weight along the entire length of the pipe. In addition, the amount of buoyancy required to support the pipe, will be greatly reduced. These factors result in a riser system which is easier to adapt to a variety of applications.

The invention will be further described below in connection with exemplary embodiments with reference to the drawing, wherein

Fig. 1 shows a perspective view of a part of a pipe according to the invention, wherein the individual layers are partly exposed to show the construction of the pipe, and

Fig. 2 shows a partly sectioned side view of a part of a similar pipe according to the invention.

As appears from Fig. 1, the illustrated pipe 1 is constructed from a number of layers 2-7. These layers include an internal load bearing layer 2 for absorbing external pressure, an internal liner 3, a first load bearing structural layer 4 for absorbing internal pressure, two additional load bearing structural layers 5 and 6 for absorbing axial and bending loads, and an external cover 7.

The internal layer 2 is required for applications where the pipe may be subjected to an external overpressure. If the internal liner 3 is not well bonded to the structural layer 4, the layer 2 will prevent collapse of the liner 3 in case of a rapid internal decompression. If the liner is well bonded to the structural layer 4, the internal layer 2 is required in order to prevent collapse on the structural layers. However, if the

structural layers have adequate resistance to external pressure, and the liner is well bonded to these, the layer 2 will not be required. This layer can be made of metal, like the carcass in traditional non-bonded flexible pipes.

The internal liner 3 is a thermoplastic tube designed to make the pipe 1 fluid-tight. The liner tube may be prefabricated by extrusion, and wound onto storage spools before assembly of the pipe components, or it may be extruded simultaneously with the assembly of the pipe. The thermoplastic material of the liner may be chosen based on the operating conditions. Potential materials are high density polyethylene, cross-linked polyethylene, polyamide or polyvinylidene fluoride (PVDF), or other suitable thermoplastic materials.

It is important that the internal liner be bonded to the structural layers. Thermal bonding is preferable, something which requires the use of a liner material which is the same as or a similar material as the matrix of the first structural layer 4. Alternatively, co-extrusion can be used, wherein a layer of a temperature resistant and chemically resistant polymer is extruded within a tube of another material which is the same as or similar to the matrix of the first structural layer 4. Alternatively, the liner may be bonded to the structural layers by chemical or mechanical means.

As stated above, the first structural layer 4 according to the invention consists of a solid layer of a polymeric material which is reinforced by long continuous fibres extending around the pipe. In this manner there is achieved a material having a high strength in the pipe hoop direction, and which is able to withstand high axial strains, i.e. transversely to the fibres.

The reinforcement fibres are supplied in yarn bundles consisting of thousands of individual fibres. The fibres may consist of any high stiffness and strength fibres. The most suitable fibre types are aramid fibres, glass fibres or carbon fibres, having a diameter in the range 5-100 μm . The composite material is formed by combining the fibre bundles with the polymer matrix. The fibres can either be individually embedded in the matrix, or bundles of the fibres may be surrounded by fibre material, so that the fibres are free to move relative to each other (bundle or cord reinforced material).

In the embodiment shown in Fig. 1, the first structural layer 4 consists of a thermoplastic low module material reinforced by bundles 8 of fibres extending around the pipe 1, each bundle 8 containing a large number of relatively movable fibres and being surrounded by, but not bonded to the thermoplastic matrix 9. However, even if this is an advantageous and presently preferred embodiment, the first structural layer, as an alternative, may be manufactured from a thermoplastic low module material in which the reinforcement fibres are well distributed and bonded to the thermoplastic matrix (Fig. 2). This results in a composite material with higher stiffness and higher strength than a cord-reinforced material, but with lesser capacity to withstand axial strain.

The fibre-reinforced thermoplastic material used in the structural layer 4, is prefabricated in tape form, the material consisting of long lengths spooled onto reels. The matrix material may be any of the polymeric materials mentioned above for the internal liner 3. If the matrix material of this layer is the same as or a similar material as the one used for the inner liner, the liner can be thermally bonded to this layer. This method is preferable. If the matrix material is different from the liner material, the liner must be chemically or mechanically bonded to this layer.

The prefabricated tapes of cord-reinforced or, alternatively, fibre-reinforced thermoplastic material are assembled to form a solid reinforced layer over the internal liner. The layer is assembled by applying discrete tapes onto a liner at an angle between 15° and 90° to the longitudinal axis of the pipe. Bonding of these tapes to the layer below can be performed in one of two ways. The tapes may be wound onto a pipe and thermally bonded to the liner at the points of contact using any of a number of heating methods, including hot air, a flame or infrared radiation. Alternatively, the tapes may be wound onto the liner without heating. In this case all layers or plies are thermally bonded simultaneously by passing the completed pipe through a series of ovens providing external heat to the pipe wall.

This first structural layer comprises several plies 10 wound at angles between 15° and 90° to the longitudinal axis of the pipe. The plies which have a winding angle at or close to 90° provide resistance to internal pressure. The plies having a lower winding angle, provide some axial stiffness and strength. The design of this

structural layer with regard to the number of layers, the thickness of the layers, and the angles of each layer is optimized for the design loads of each application.

Alternatively, the solid structure of layer 4 may be manufactured from other composite materials. These could comprise any composite with a primary reinforcement in the circumferential or hoop direction of the pipe, and with high axial strain capacity.

As mentioned, the two additional structural layers 5 and 6 added on the outside of the solid structural layer 4, are arranged to provide resistance to axial and bending loads. In order that the bending stiffness of the pipe 1 shall not be increased to a substantial degree, these layers must be non-bonded, and each layer therefore consists of a plurality of individual strips 11 which are wound around the pipe, but are not bonded to the adjacent strips or to the layers above or below these.

In the embodiment of Fig. 1, the pipe 1 is provided with two additional layers 5 and 6, but there may possibly be provided four layers. As suggested in the Figure, the individual strips 11 are wound at alternating positive and negative angles to the longitudinal axis of the pipe. These angles can be in the region 15° - 60° .

The strips of these layers may be manufactured from fibre-reinforced thermoset materials or fibre-reinforced thermoplastic materials. The most suitable fibre reinforcements are the same as for the cord-reinforced thermoplastic material. For a thermoset matrix, epoxy is one suitable material. The candidate thermoplastic matrix materials are the same as for the cord-reinforced material.

The application method of these layers depend on the matrix material chosen. For fibre-reinforced thermoset strips, the following manufacturing possibilities exist:

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- * The strip are manufactured and simultaneously wound onto the pipe using wet filament winding and rapid cure after application.
- * Thin plies are prefabricated, cured and stored on reels. These plies are wound onto the pipe, with several plies applied on top of each other to build up the required thickness of the strip. The plies are bonded to each other using an adhesive, or could be left unbonded.

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* Thin plies are prefabricated, and partially cured, and stored on reels. These plies are then wound onto the pipe, with several plies applied on top of each other to build up the required thickness. Heat is then applied to the finished layer to complete the cure of the thermoset material.

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If fibre-reinforced strips of a thermoplastic material are used, the following assembly method may be used:

* Thin plies of fibre-reinforced thermoplastic material are prefabricated and stored on reels. These plies are then wound onto the pipe, with several plies applied on top of each other to build up the required thickness. The plies are bonded by applying heat at the points of contact. Alternatively, the plies may be left unbonded.

15 The external cover 7 applied to the pipe 1, provides tightness against external fluids, and also resistance against scraping, abrasion, shock and biological growth. This cover may be manufactured of the same materials as for the internal liner 3. The cover may be applied by being extruded over the finished pipe in a conventional manner.

20 In Fig. 2 there is shown an embodiment of a pipe 12 according to the invention which in all essentials corresponds to the embodiment in Fig. 1, and wherein similar components in the two Figures are designated by the same reference numerals. The difference is that the pipe 12 is without any internal layer within the internal liner 13, and that the first structural layer 14 is of another design than in the pipe 1 in Fig. 1. Thus, Fig. 2 shows the aforementioned embodiment wherein the solid structural layer 14 consists of a thermoplastic material in which the reinforcement fibres 15 are well distributed in the thermoplastic matrix 16.

Example

30 An example of design parameters, dimensions and materials for a pipe according to the invention is given below.

Pipe design parameters

- * Internal diameter = 200 mm
- * Internal pressure = 50 MPa

Internal liner

- 5 * Purpose: To provide an internal fluid-tight barrier
- * Material: Polyamide 11 (thermoplastic polymer)
- * Thickness: 5 mm

Pressure load bearing layer

- * Purpose: To withstand internal pressure loads
- 10 * Material: Aramid bundle-reinforced polyamide 11
- * Form: A solid composite layer consisting of multiple layers of cord-reinforced or bundle-reinforced polyamide 11, wound at alternating angles of $\pm 80^\circ$ relative to the longitudinal axis of the pipe. All layers are consolidated into a solid composite layer
- * Thickness: 20 mm

15 Axial and bending load bearing layers

- * Purpose: To withstand axial and bending loads
- * Material: Carbon fibre unidirectionally reinforced epoxy
- * Form: Two unbonded layers, each consisting of multiple discrete strips of unidirectionally reinforced epoxy. The two layers are wound onto the pipe at angles of
- 20 $+35^\circ$ and -35° relative to the longitudinal axis of the pipe.
- * Thickness: 6 mm

Cover

- * Purpose: To provide an external fluid-tight barrier, and in addition to protect against scraping, abrasion, shock and biological growth
- 25 * Material: Polyamide 11 (thermoplastic polymer)
- * Thickness: 5 mm

Pipe weight

- * Dry weight = 27,8 kg/m
- * Submerged weight = 3,0 kg/m

P a t e n t c l a i m s

1. A flexible lightweight high pressure pipe for riser or pipeline
5 applications, especially offshore, comprising an internal liner (3), a first structural layer
(4) applied to the internal liner, for absorbing pressure loads, one or more structural
layers (5, 6) applied to the first structural layer (4), for absorbing axial and bending
loads, and a fluid-tight external cover (7), wherein at least the first (4) and the additional
(5, 6) structural layers are manufactured from a lightweight composite material
10 consisting of a fibre-reinforced polymer matrix,
c h a r a c t e r i z e d i n t h a t the first structural layer (4) is a solid layer which is
reinforced by long continuous fibres (8) extending around the pipe (1), so that the layer
has a high strength in the hoop direction of the pipe, and that each of the additional
structural layers (5, 6), as known per se, consists of a plurality of individual strips (11)
15 reinforced by fibres extending essentially in the longitudinal direction of the strips, and
which are wound around the pipe (1), but are not bonded to the adjacent strips (11) or to
the layers (4, 7) above or below these.

2. A pipe according to claim 1,
c h a r a c t e r i z e d i n t h a t also the internal liner (3) and the external cover (7)
20 are manufactured from a polymeric material having a low module.

3. A pipe according to claim 1 or 2,
c h a r a c t e r i z e d i n t h a t the first structural layer (4) consists of a thermoplastic
low module material which is reinforced by bundles (8) of fibres extending in the
direction around the pipe (1), each bundle (8) containing a large number of mutually
25 movable fibres and being surrounded by, but not bonded to the thermoplastic matrix (9).

4. A pipe according to claim 1 or 2,
c h a r a c t e r i z e d i n t h a t the first structural layer (14) is manufactured from a
thermoplastic low module material in which the reinforcement fibres (5) are well
distributed and bonded to the thermoplastic matrix (16).

30 5. A pipe according to claim 3 or 4,

characterized in that the fibre-reinforced thermoplastic material consists of prefabricated strips (10) wound onto the internal liner (3) with an angle of 15° to 90° to the longitudinal axis of the pipe (1).

6. A pipe according to claim 5,
5 characterized in that the strips (10) are thermally bonded to the internal liner (3), this consisting of a pipe of the same or a similar thermoplastic material as the material in the first structural layer (4).

7. A pipe according to claim 5,
characterized in that the strips (10) are thermally bonded to the internal
10 liner (3), this consisting of two layers of which an external layer consists of the same thermoplastic material as the material in the first structural layer (4), and an internal layer consists of a different material which is temperature and corrosion resistant.

8. A pipe according one of the preceding claims,
characterized in that the matrix material of the additional structural layers
15 (5, 6) consists of a thermoplastic material.

9. A pipe according to one of the claims 1-7,
characterized in that the matrix material of the additional structural layers
(5, 6) consists of a thermoset plastic material.

10. A pipe according to claim 8 or 9,
20 characterized in that the strips (11) of the additional structural layers (5, 6) are wound at alternating positive and negative angles between 15° and 60° to the longitudinal axis of the pipe (1).

11. A pipe according one of the preceding claims,
characterized in that the fibres consist of glass, aramid or carbon, having a
25 diameter in the range 5 - 100 µm.

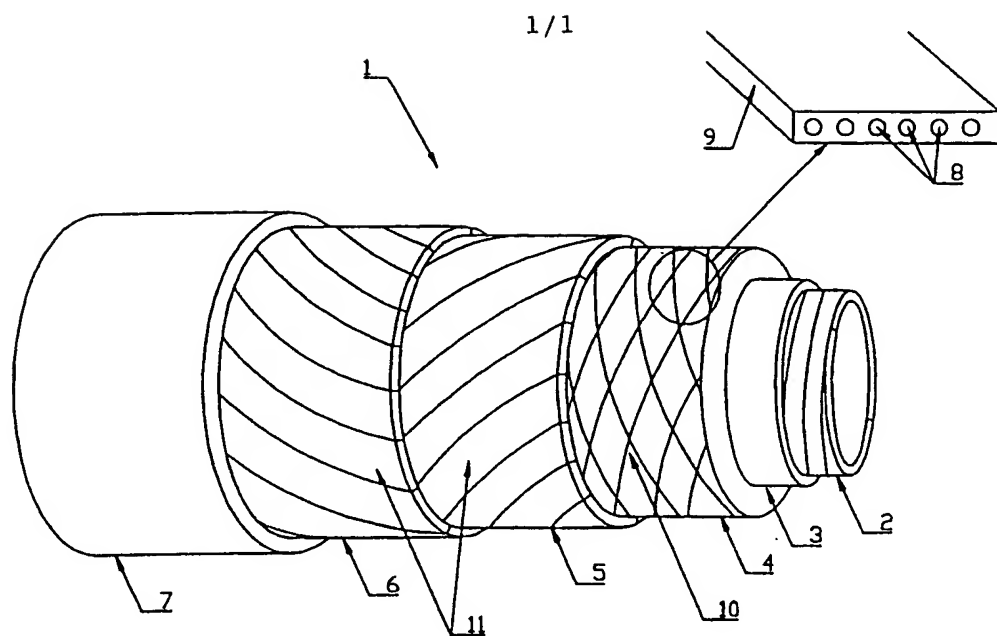


Fig. 1

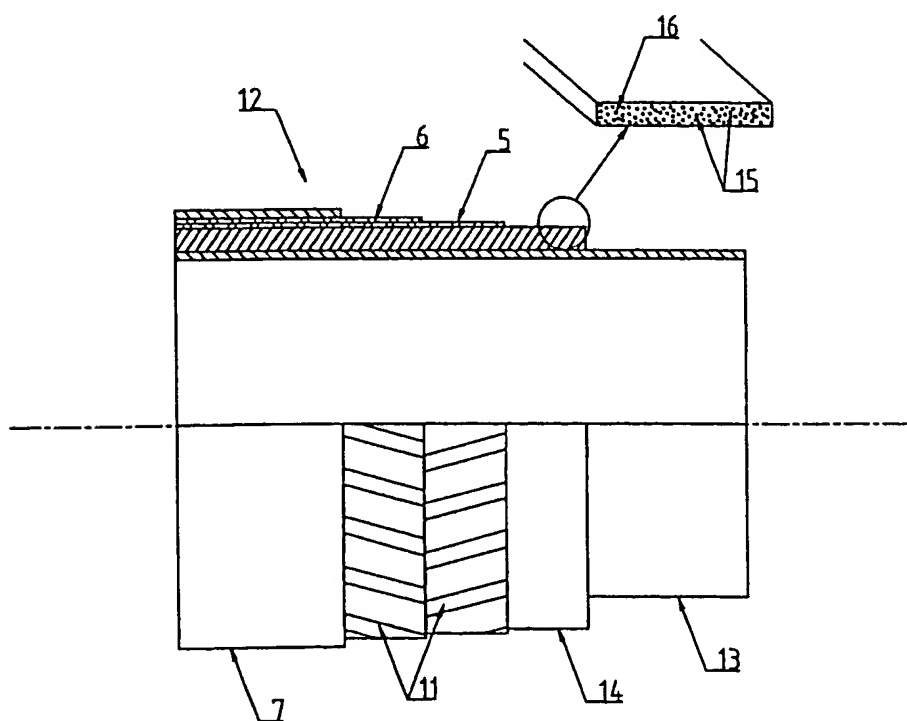


Fig. 2

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 00/00158

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: F16L 11/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: F16L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9845634 A1 (EXXON RESEARCH AND ENGINEERING COMPANY), 15 October 1998 (15.10.98), figure 1, abstract --	1
A	EP 0644364 A1 (STRUCTURAL POLYMER SYSTEMS LTD), 22 March 1995 (22.03.95), figure 5 --	1
A	DE 2135377 A (ORSZAGOS GUMIIPARI VALLALAT), 1 February 1973 (01.02.73), figure 1 --	1
A	US 5261462 A (WOLFE ET AL), 16 November 1993 (16.11.93), claim 1 -----	1

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

08/05/00

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Patent document cited in search report			Publication date	Patent family member(s)	Publication date
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EP	0644364	A1	22/03/95	GB 2282203 A	29/03/95
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